TRACE ELEMENT COPPER DISTRIBUTION AND AREAL GEOLOGY IN A PORTION OF THE CLEARWATER MOUNTAINS, ALASKA

A

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ABSTRACT

The study concerns that portion of the Clearwater Mountains defined by north latitudes 63° 03' and 63° 08' and west longitudes 147° 09' and 147° 30'.

Outcrop within the area consists predominantly of a sequence of intercalated andesitic and basaltic flows. Sedimentary rocks are present but comprise a very small percentage of the total section. Dikes and a small pluton are also present. The prevailing attitude of the volcanic and sedimentary rocks is east-northeast with a consistent north dip. A Triassic age is accepted for the volcanic and sedimentary rocks.

Areal and local sampling indicates that all rock types are abnormally high in trace copper content, and average background is 1000 ppm. Copper distribution suggests a syngenetic origin. Frequent small copper deposits crop out along the north side of the area. The deposits are epigenetic and are structurally controlled. The origin of these deposits may have potential exploration significance.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

Location and Accessibility

The Clearwater Mountains are located between the Susitna and Maclaren Rivers on the south flank of the Central Alaska Range, Alaska (Plate I). The area discussed in this report consists of a southern portion of the Clearwater Mountains that is specifically defined by north latitudes 63° 03' and 63° 08' and west longitudes 147° 09' and 147° 30'.

The map area is accessible by road and air. The Denali Highway, which begins at Paxon, Alaska, runs along the south and a portion of the west boundary of the area. The highway is an improved gravel road suitable for any vehicle. The north side of the area is accessible via a cat-trail along the south side of Windy Creek.

Two private landing fields are present, one is located near Susitna Lodge at the west end of the area, and the other is located at the head of Windy Creek. In addition several lakes are suitable for float equipped light aircraft.

Physiography

In the map area the Clearwater Mountains rise abruptly to form an easterly trending range of comparatively low but very rugged hills. The mountains have been dissected by alpine glaciation to form a series of sharp peaks and narrow rugged ridges separated by typical U-shaped glaciated valleys (Fig. 1

and 2). The maximum relief in the area is approximately 3600 feet. The highest peak (elevation 6200) is located in the east central portion of the area. Mean peak elevation is 5600 feet.

Slopes are very steep and grades of fifty percent are common. The south facing slopes are mantled with glacial debris to an average elevation of 3300 feet. Glacial debris on north facing slopes extends up to an average elevation of 3500 feet. The upper slopes consist of angular talus in which the individual rock fragments range from less than one inch to more than ten feet. The talus slopes are unstable and rock slides are common. Bedrock exposures are confined to the higher elevations.

Windy Creek, the major stream of the map area, is a westerly flowing tributary of the Susitna River (Plate II). Streams draining the northern slopes all occupy glaciated valleys and all are tributaries to Windy Creek. Small tarns are common at the head of these streams. The streams draining the southern slopes occupy their own V-shaped valleys and are tributaries of the Susitna River. Alpine and Waterfall Creeks occupy valleys which have been glaciated in their upper portions.

Rock weathering is largely restricted to those agents associated with a periglacial environment. The chemically weathered rind on cut samples never exceeds two millimeters.

Exploration and Development

Within and immediately adjacent to the study area, only two prospects have received attention beyond a surface examination. These two prospects, the

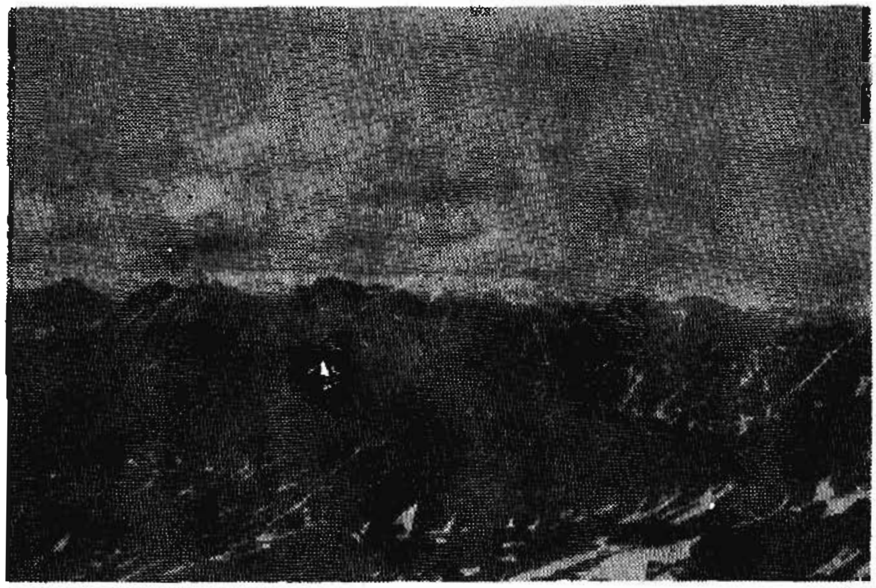

Figure 1. View of Clearwater Mountains. Photo taken from station 5-5 looking northeast. Alaska Range in background.

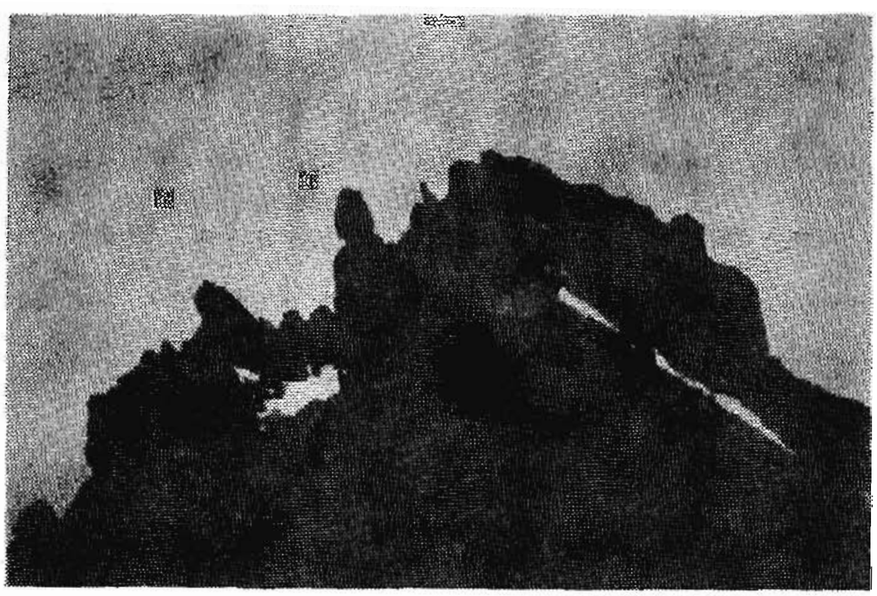

Figure 2. Typical ridge crest at station 3-5, Clearwater Mountains, as viewed north.

Greathouse prospect and the Denali prospect, are both copper properties. The Greathouse prospect will be discussed later in this report. The Denali prospect, located in the divide between Windy and South Fork Creeks, is currently being explored.

Mineral development in adjacent areas includes extensive placer mining and lode prospecting in the Valdez Creek district and the Kathleen-Margaret copper prospect on the Maclaren River. The activity in the Valdez Creek area has been described by Ross (1933). At the present time two groups are still actively prospecting this area. For a description of the Kathleen-Margaret prospect the reader is referred to Chapman and Saunders (1954) and MacKevett (1964).

Previous Work

Previous work in the study area includes Moffit (1912), Chapin (1918), Capps (1940) and Kaufman (1964). Of the four, Kaufman's work was the most detailed. His survey included bedrock mapping, geochemical sampling of stream sediments and limited petrography.

Present Investigation

Small copper occurrences frequently crop out in the altered volcanic rocks of the study area. The purpose of this investigation was to examine the lithology, structure and trace copper distribution in an attempt to define the limits to which these parameters have influenced copper mineralization.

Field work in the area was done during the period 14 June 1966 to 3 August

1966 and consisted of mapping on a scale of four inches to the mile and sampling along controlled traverse lines. Rock specimens were taken at 1000 foot intervals for the areal grid but at much closer and variable intervals for the local traverses.

Laboratory investigations included megascopic and petrographic analyses. The sodium cobaltinitrite method was used on the intrusive rocks for potash feldspar determination. Mineralized specimens were studied as polished sections and slabs. All specimens taken in the field were analyzed for trace copper content, using a semiquantitative spectrochemical technique.

Acknowledgements

I am indebted to the Mineral Industry Research Laboratory, University of Alaska, for financial support and use of analytical equipment without which this project would not have been possible. I wish to thank my thesis advisor, Dr. H.D. Pilkington, for his invaluable assistance throughout the investigation. I thank Dr. D.J. Cook and Dr. R.B. Forbes for reviewing the manuscript and for their helpful comments during various phases of the project. Thanks also go to Mr. L.E. Heiner, M.I.R.L., for comments and assistance during the spectrochemical investigation.

I wish to express my appreciation to the following individuals for assistance, both technical and logistical, during the field study: Mr. and Mrs. D.L. Thompson and Mr. C.R. Greathouse of Susitna Lodge, Mr. D. Huber of the Tennessee Corporation, and Mr. Charles Monroe of Northland Mines. Mr. J.R. Henry served as field assistant and Mrs. L.E. Heiner typed the manuscript.

REGIONAL GEOLOGIC SETTING

The Clearwater Mountains are a small range of mountains between the Maclaren and Susitna Rivers on the south flank of the Central Alaska Range (Plate I). The central and southern portions of the mountains consist of two east-northeasterly trending belts of volcanic and sedimentary rocks. The northern portion of the Clearwater Mountains consists of large bodies of intrusive rocks. (Moffit, 1912)

North of the study area, and continuing for approximately four to six miles, is a sequence of dominantly sedimentary rocks that includes limestone, carbonaceous limestone, argillite and interbedded andesitic flows. Moffit (1912) suggests that the contact relationship between this sedimentary sequence and the underlying volcanic sequence in the vicinity of Coal Creek is either a fault or a depositional unconformity.

Bedrock within the study area consists of andesitic to basaltic volcanic flows. Sedimentary and tuffaceous rocks are interbedded with the flows in the vicinity of Raft Creek; however, the sediments comprise a very small percentage of the total section. In the map area the stratigraphic relationship between the volcanics and the sedimentary rocks of the central Clearwater Mountains is obscured by the glaciated valley of Windy Creek; however, structural concordancy between the two sequences suggests a conformable relationship.

Moffit (1912) shows the volcanic sequence continuing eastward for sixty-six miles from the Susitna River, in an arcuate-shaped outcrop pattern convex toward the north. Rose (1965) describes the volcanic rocks of the Paxon area as follows:

> In thin section, the least altered specimens consist of porphyritic basalt composed of sparse plagioclase phenocrysts in a matrix of plagioclase and augite with an intergranular texture. In all specimens examined microscopically, the plagioclase is albite, even when the augite is completely unaltered. Most samples contain moderate amounts of epidote and variable amounts of calcite which may have formed from calcium released by albitization. Chlorite is the most common mineral in the amygdules, but calcite, epidote and quartz were also noted.

Rose has named this rock unit the Amphitheatre basalt and estimates its thickness on Paxon Mountain as being at least 2000 feet. On Sugarloaf Mountain, east of Tangle Lakes, the Amphitheatre basalt grades downward through andesitic tuffs and flows into a sequence of tuffaceous sediments and diabase (Rose, 1966).

Previous workers (Moffit, 1912 and Rose, 1965) have pointed out the similarities in lithology, stratigraphic position and possible age between the Amphitheatre basalt and the Nikolai greenstone farther to the east. The equivalency of these two rock units, however, has not been established.

BEDROCK GEOLOGY

Volcanic Rocks

Occurrence and Distribution

Volcanics are the dominant rock type of the area. With the exception of a minor quantity of interbedded sediments in the vicinity of Raft Creek, the volcanics form a continuous sequence which extends from Windy Creek south to the Denali Highway (Plate II). The sequence consists of interlayered andesites and basalts with subordinate tuff and glassy flow units. The latter two rock types were only detected south of Alpine Creek along the south margin of the area.

Individual flows are extremely difficult to differentiate and are best seen in near vertical cliffs when viewed from a distance. The flows appear to range in thickness from a few feet to 100 feet.

Petrology

The volcanic sequence consists of the following compositional rock types in order of decreasing abundance: andesite, basalt, greenstone and tuff.

Andesite

Andesite is the dominant rock type of the sequence. These rocks are usually aphanitic to fine-grained and may be either amygdaloidal or porphyritic. Medium-grained (maximum length 1 mm) rocks were also encountered and are thought to be cores of thick flows; however, due to limited outcrop this could not always be proven. The rocks vary in color from light to dark green, dull red, purple or black. The color of an individual unit is usually consistant along both dip and strike.

In thin section, the andesites typically show an intergranular texture. Primary minerals consist of plagioclase, augite, olivine, hornblende and magnetite or ilmenite. Secondary albite, sericite, epidote, chlorite, quartz, magnetite, leucoxene, sphene, hematite and carbonate may be present in varying percentages dependent upon the degree of alteration to which the rock has been subjected.

Plagioclase makes up 60 to 70 percent of the andesites. It typically occurs as well developed, lath-shaped euhedral crystals that are commonly twinned according to the albite, pericline and carlsbad laws. The plagioclase ranges from An_{23} to An_{43} with a composition of An_{32} to An_{35} being the most common. In porphyritic andesites the phenocrysts are plagioclase and these are commonly slightly more calcic than the plagioclase of the groundmass. The plagioclase is highly susceptible to alteration and is commonly sericitized and decalcified to form the secondary minerals albite, epidote, quartz and carbonate.

Augite is the most abundant mafic mineral of the andesites and comprises from 25 to 40 percent of the rock. It occurs as small, usually equidimensional grains intersertal to the plagioclase. The grains occasionally achieve a size comparable to that of the plagioclase and in this form, they are usually euhedral. The pyroxene is much more stable than the plagioclase and in weak to moderately altered rocks is little affected. When altered, it is converted into chlorite and magnetite.

Olivine and hornblende rarely occur in these rocks. Olivine, when it is present, occurs as very small, equidimensional grains which never exceed one percent of the rock. Hornblende is usually present as uralitic rims on pyroxene and as such should be classified as dueteric; however, rare grains of prismatic hornblende were observed.

Magnetite and/or ilmenite occur as a minor constituent in all of the andesites. It may occur in primary form or as an alteration product of pyroxene and/or olivine.

Some of the andesites contain epidote, chlorite, quartz, calcite and, occasionally, bornite and native copper in amygdules. The zeolite, natrolite, was recognized in one specimen.

Andesitic rocks containing abundant glass were detected in the lower portion of the section in the vicinity of Alpine Creek, but are not a common rock type. The glassy units are characteristically strongly altered and their outcrops show good rock cleavage. Primary flow structures are still visible in thin section.

<u>Basalt</u>

Basaltic rocks occur as intercalated flows within the andesites. They are definitely subordinate in frequency of occurrence. The basalts are always dark green or black in color. These rocks are usually very fine-grained and sometimes slightly porphyritic.

The constituent mineralogy, both primary and secondary, of the basalts, is similar to the mineralogy of the andesites and the distinction between the two is based upon petrographic criteria. In the basalts, the anorthite content of the plagioclase exceeds An_{50}, and the highest observed was An_{62}. Pyroxene frequently exceeds fifty percent of the rock and is generally coarser grained than in the andesites. Olivine may be present in amounts of one to three percent and constitutes a varietal accessory mineral.

The presence and abundance of secondary minerals is again a function of the degree of alteration.

Greenstone

Greenstones represent the strongly altered equivalent of the andesites and basalts. In the field, they are easily recognized by their light to dark green color, lower specific gravity and abundant megascopic epidote and chlorite. Greenstones usually occur in association with shear zones and highly fractured areas.

Mineralogically the greenstones consist of untwinned plagioclase (albite and albite-oligoclase), abundant epidote and chlorite, quartz, relict pyroxene, sphene, magnetite, hematite, sericite, carbonate and hydrous iron oxide.

Texturally the greenstones may or may not reflect the texture of the original rock. The predominant texture is random except in the more glassy rocks where chlorite, derived from altered glass, parallels the original flow structure. Stringers of quartz, carbonate, epidote and chlorite are common.

Tuff

Tuffs were found in the lower part of the section south of Alpine Creek (Plate II).

The tuff consists of crystals of plagioclase and embayed quartz, non-cognate rock fragments, and considerable opaque material set in a fine-grained groundmass of altered glass. The rock is strongly altered and shows good shear cleavage. Secondary minerals present are chlorite, sericite, illite (?), quartz, carbonate and hematite.

The rocks are laminated and some of the opaques appear to be carbonaceous, which suggests a water-laid origin.

Sedimentary Rocks

Occurrence and Distribution

The outcrops of sedimentary rocks are confined to the area of Raft Creek (Plate II). The lateral extent of these units is unknown, due to poor exposures. No sedimentary rocks were found along traverse no. 3 and one thin unit of chert was found at the southern end of traverse no. 9 (Plate III). With the exception of a limestone unit reported near the Greathouse property by Kaufman (1964), no sediments were found in the north half of the map area. In the Raft Creek area, the sediments are intercalated with the volcanics and consist predominantly of black shale with lesser quantities of mudstone and sandstone.

Petrology

Black Shale

Black shale is the most frequently encountered sediment. The rock is typically black, fissile, and frequently pyritiferous. Clay (illite?) and carbonaceous material make up 98 percent of the rock. The remaining two percent consists of silt-sized, angular to sub-angular grains of quartz and feldspar.

Other minerals are present but are too fine grained to be identified.

No apparent hornfelsing was observed in the thin sections studied but some specimens are very dense, suggesting silicification.

Sandstone

Sandstone occurs as interbedded narrow lenses within the shale. They are very fine to fine-grained, poorly sorted and typically show graded bedding.

Petrographically the sandstone consists of approximately 60 percent angular to sub-angular quartz and feldspar. The matrix is dominantly clay with subordinate amounts of carbonaceous material and accessory carbonate. The sandstone is a feldspathic graywacke (Pettijohn, 1957). In the specimen examined, secondary chlorite, epidote and randomly oriented sericite indicate slight hornfelsing.

Mudstone

The mudstones are differentiated from the shales by the lack of fissility in the former. Normally they contain less carbonaceous material than the shales and are lighter in color.

Petrographically the rock contains approximately 90 percent clay-sized material, and equal amounts of silt-sized quartz and feldspar make up the remaining ten percent. The rock is hornfelsed and original textures are largely obliterated. One specimen of mudstone shows sub-angular intraclasts which are compositionally identical to the matrix. The intraclasts are as large as 15 millimeters in diameter and can be seen in hand specimen on a cut surface. These intraclasts probably represent flucuating current velocities in the depositional environment.

Chert

The only occurrence of chert found during this investigation is located on the southern end of traverse no. 9 (Plate III).

At this location the chert is intercalated between two volcanic units. None of the previously described sedimentary rocks are present in the vicinity.

The chert is light gray in color and in hand specimen appears reasonably pure. The rock was not analyzed petrographically.

Summary of Volcanic and Sedimentary Rocks

The rocks of the area are the product of continuous volcanism with minor interruptions during which the sediments were deposited. The region was tectonically unstable.

Irregular flow surfaces, the presence of one flow breccia and the distinct lack of pillow structures suggests that the volcanic flows were laid down in a sub aerial environment. The sediments and tuffs are probably the product of deposition in a shallow near shore environment. The basins of deposition were depressions on the surface of the volcanics. Such basins of deposition in a volcanic area are characterized by reducing environments.

The sequence of rocks north of Windy Creek indicates a general submergence of the area which was accompanied by sedimentary deposition that was occasionally interrupted by volcanic activity.

Intrusive Rocks

Occurrence and Distribution

Intrusive rocks occur as dikes, plugs and a small pluton. Sills were not recognized but their presence is suspected. The occurrence of intrusive rocks appears to be limited, but they may be more common than this survey shows.

Dikes occur throughout the area but are more abundant on the north side. They may be aphanitic or phaneritic. One aphanitic dike was amygdaloidal.

A small gabbro plug was found on the eastern end of traverse no 4. (Plate III). Although here referred to as a plug, it may well be a sill with short lateral extend.

A small pluton is located in the drainage of Raft Creek (Plates II and IV). An irregular outcrop pattern of intrusive versus volcanic rocks suggests that these outcrops represent the upper portion of an intrusive body currently being exposed by erosion. Kaufman (1964) reports a small quartz monzonite body one mile south of the Denali Highway at mile 70.

Petrology

Quartz Bearing Diorites

Quartz bearing diorites constitute the dominant rock type of the Raft Creek pluton. Such rocks also occur as dikes associated with the pluton and as a single dike on the Greathouse property (Plate III). In the Raft Creek drainage, quartz bearing diorites intrude a sequence of interbedded volcanic and sedimentary rocks. The outcrop is interpreted as the roof of a pluton. A satellite outcrop of medium-grained crystalline diorite was also found high on the slope to the west of Raft Creek, which probably represents an apophysis of the main pluton.

In outcrop the diorite is well jointed, commonly slickensided and frequently cross-cut by quartz veins. The rock itself is strongly altered but possesses a recognizable chilled border. Slight hornfelsing is recognized in adjacent sediments.

Petrographic study shows the diorite to be strongly altered and most of the primary minerals have been converted to secondary alteration products. The modal analysis shown in Table I is believed to be representative of the quartz bearing diorites prior to alteration. The analysis is based upon a study of four thin sections, and percentages cited represent visual estimates.

TABLE I

Modal analysis of quartz bearing diorites from the Raft Creek pluton.

Plagioclase (An_{30} to An_{45})	55-60%
Augite	35-40%
Quartz	<3
Magnetite or Ilmenite	<2
Hornblende and Uralite	<1
Sphene	<1
Apatite	<1

Most of the original plagioclase has been sericitized and decalcified. The products of decalcification are pistacite, chinozoisite, quartz, albite and carbonate. Minor secondary plagioclase that is subhedral and occasionally twinned has formed. The composition of the new plagioclase is approximately An_{12} and it is characteristically unaltered.

The diorite contains both primary and secondary quartz. The secondary quartz has been, in part, derived from the decalcification of the plagioclase and in part, introduced.

Primary hornblende is a rare constituent of these rocks. When present, it is altered to chlorite.

The pyroxene of the diorite characteristically alters to chlorite and magnetite. Occasionally uralite rims occur, but they are probably deuteric. Clinochlore and pennine occur as common alteration products of the pyroxene and hornblende. A third chlorite mineral occurs as an alteration product and also as independent porphyroblasts, which appears to have formed later than either the clinochlore or pennine.

Four representative chips of the pluton were stained with sodium cobalinitrite. The standard technique was employed and the staining procedure failed to disclose the presence of potassium feldspar in any of the chips. A sample from the satellite outcrop, believed to represent a late dike, indicates the presence of potassium feldspar in amounts less than three percent.

Although strongly altered, the original diabasic texture of the diorites is still apparent. In specimens taken from the marginal zones, micrographic intergrowths of quartz and plagioclase are common.

The intrusive nature of these rocks is suggested by the irregular outcrop pattern, chilled border zones, slight hornfelsing of adjacent sediments and the presence of compositionally similar dikes in the adjacent country rock. The quartz bearing diorites are most probably the product of crystallization from a saturated basic magma that was emplaced and crystallized at a relatively shallow depth. The composition of the associated dike suggests an alkalic differentiate.

The jointed and sheared nature of the outcrops and the high degree of alteration in the rocks indicates that they were emplaced prior to the regional folding and thermal alteration.

Gabbro

Gabbro occurs as a small plug on the eastern end of traverse no. 4 (Plate III).

The gabbro is a medium-grained rock with a sub-ophitic texture. Frequent aggregates of plagioclase crystals give the rock a glomeroporphyritic appearance in hand specimen.

The texture of the gabbro indicates that it cooled rather uniformally at a relatively shallow depth. Compositionally it is identical to the previously described basalts (Table II) but its mode of occurrence and exceptionally low degree of alteration indicate that it is considerably later.

TABLE II

Estimated mode of one thin section
of gabbro from traverse no. 4.

Plagioclase (An_{51})	60%
Augite	31
Magnetite or Ilmenite	5
Chlorite	<2
Olivine	1
Uralite	<1
Sphene	<1
Clinozoisite	tr.

This plug may have been a feeder for the volcanic rocks that occur in the predominantly sedimentary section north of Windy Creek.

Alteration

Rock alteration within the area is not uniform. It may vary from weak to strong along the same traverse. Contacts between alteration types are usually gradational.

The effects of alternation are best seen in the volcanic and intrusive rocks. With the exception of minor hornfelsing the sediments are not significantly altered.

Based upon a study of 42 thin sections, four levels of alteration are recognized. A numerical value is arbitratily assigned to each of the four levels and this value is henceforth referred to as the alteration index.

Weak Alteration (1)

The plagioclase in the weakly altered rocks appears fresh. There is little to no sericitization and/or saussuritization. Alteration of the pyroxene, if present, is very minor. Carbonate is not present. Secondary quartz occurs only in amygdules. These rocks never contain greater than five percent chlorite by volume. The chlorite occurs as discrete grains and appears to have been introduced.

Moderate Alteration (2)

The plagioclase in moderately altered rocks is commonly sericitized and always partially decalcified. Epidote, carbonate and secondary quartz are common minor constituents of the rock. Chlorite now represents a major rock constituent ($>5\%$), and occurs as both independent aggregates and as an alteration product of the mafics. The pyroxene are little affected by the alteration. Hornblende, if present, is chloritized. The rock retains a good hypidiomorphic-granular texture.

Strong Alteration (3)

Rocks subjected to strong alteration contain greater than ten percent chlorite and/or epidote. All primary constituents are altered but the original rock texture is still preserved. Carbonate and secondary quartz are common and occur interstitially and as small cross-cutting veinlets.

The strongly altered rocks represent the transition from moderately altered rocks to greenstone.

Very Strong Alteration (4)

The very strongly altered rocks are represented by the greenstones. In these rocks chlorite and epidote are ubiquitous. Secondary anhedral albitic plagioclase is the dominant plagioclase. Small cross-cutting veinlets of carbonate, quartz, epidote and chlorite are common. Sericite, if present, is sufficiently coarse-grained to be called muscovite.

Figure 3, based upon microscopic and megascopic examination of 70 samples, illustrates the frequency of occurrence of the different alteration levels. Each sample represents a station in the areal sampling pattern.

In the facies classification of hydrothermally altered rocks proposed by Burnham (1962), all the above alteration levels would be classified as members of the propylitic sub-zone of the argillic facies.

In some of the greenstones the texture of the original rock is still recognizable; in most specimens it is not. The predominant texture of the altered rocks is random, and it is usually pseudomorphous after the original rock texture.

The only rocks that tend toward an oriented fabric are the glassy units. These rocks typically possess primary flow structures and chlorite, developing from the glass, is parallel to the original structure.

In all specimens examined the alteration is static thermal. The presence of aqueous fluids associated with the alteration is indicated by the porphyroblasts of chlorite, the occurrence of secondary minerals as fracture fillings and amygdules of secondary minerals in which there is no visible interaction across the interface between vesicle wall and host rock. The chemical composition of these fluids, as demonstrated by the secondary minerals produced, included magnesium, aluminum, iron, silica, calcium, carbon, copper, sulfur and water. The composition and chemical properties of the fluids was probably variable and subject to change. This would be, in part, dependent upon the composition of the rocks through which the fluids had circulated and intermixing with other fluids.

A possible source of the thermal energy and fluids that produced the alteration in these rocks is renewed volcanic activity that resulted in the flow rocks which occur in the stratigraphically higher section north of Windy Creek. The presence of the relatively weakly altered gabbro plug on traverse no. 4 (Plate III) supports this.

Alteration that may be directly attributed to the emplacement of the Raft Creek pluton is not apparent from this study. The occurrence of only slight hornfelsing in adjacent pelitic rocks indicates that the temperature of emplacement of the pluton was low. In addition, the strongly altered nature of the intrusive rock indicates its presence prior to regional alteration.

The more intensely altered rocks (alteration index 3 and 4), are almost

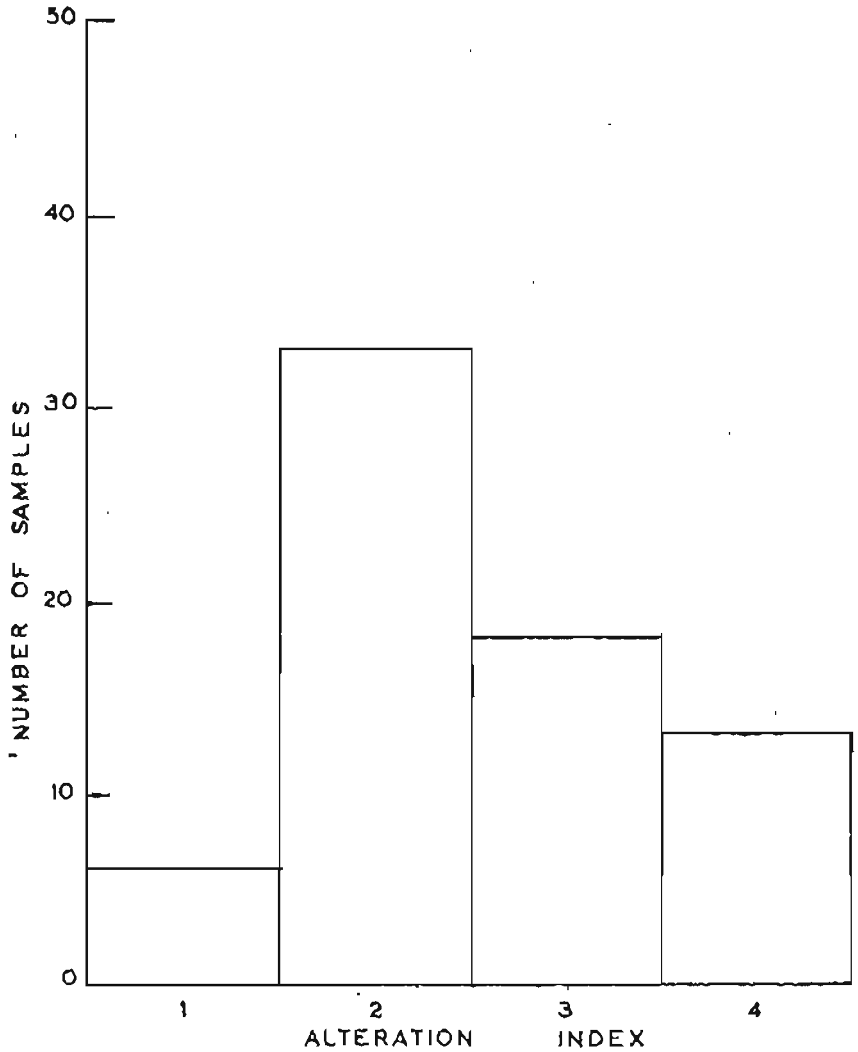

Figure 3. Histogram relating number of samples to different degrees of alteration. Based upon examination of 70 samples.

always associated with shear zones and highly fractured areas. This association suggests either one or a combination of the following: (1) the alteration is structurally controlled; or (2) the altered rocks, being less competent than the unaltered rocks, have controlled the location of yielding.

Structure

Individual flow units are best seen in near vertical cliffs when viewed from a distance (Fig. 1 and 4). The surface separating individual flow units is usually very irregular and attitudes measured on these surfaces are not representative of the unit as a whole. Attitudes are easily obtained on the sediments but the occurrence of these rocks is too limited to provide areal information.

The prevailing attitude of the volcanic and sedimentary rocks is east-northeast with a consistent north dip. The strike of the rocks varies slightly and the angle of dip appears to increase toward the north (Fig. 5 and Plate II). No south dips were observed.

In the western portion of the area, an easterly trending shear zone extends along the north side of the mountains. The zone is essentially vertical and its width varies from approximately 100 feet to as much as 1000 feet (Plate II). The zone is characterized by relatively closely spaced individual subzones of highly fractured and sheared rock. The subzones frequently contain networks of brecciated vein material consisting of iron bearing carbonate and subordinate quartz. Residual accumulations and downslope movement of the weathered vein material produce iron stained areas considerably wider than the actual subzone.

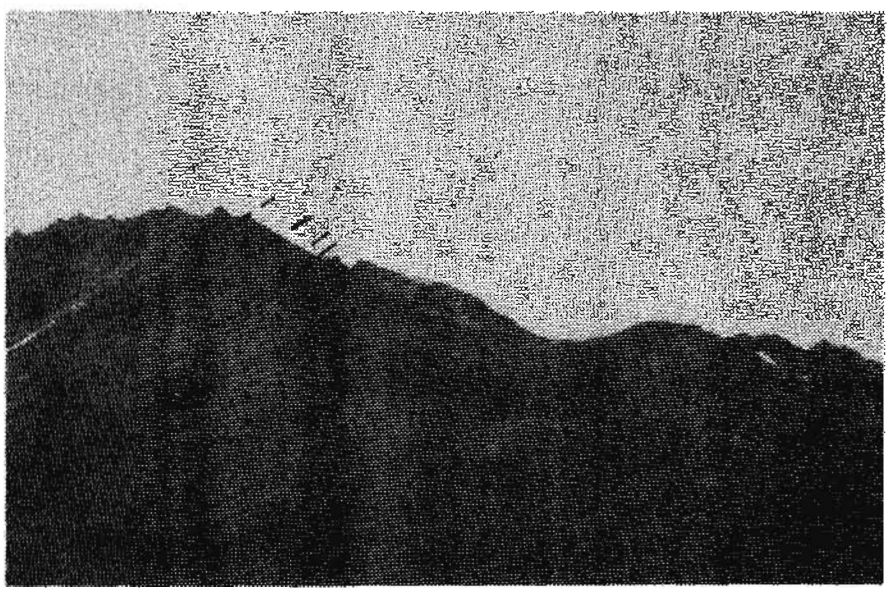

Figure 4. Layering in the volcanic rocks on the ast side of Swampbuggy Lake, Clearwater Mountains. Dotted lines delineate layering.

Striations on slickensided surfaces indicate that the movement in this zone has been both vertical and horizontal. The magnitude of displacement could not be determined but appears to be small. Displaced and brecciated veins indicate recurrent movement within the shear zone.

Smaller shear zones and highly fractured areas occur throughout the area. They appear to be randomly oriented and, where traceable, are discontinuous along strike.

Jointing is well developed in all outcrops. A plot of 93 joints recorded from the volcanic, sedimentary and instrusive rocks indicates two major conjugate joint sets (Fig. 6). The strike frequency distribution (Fig. 7) of the two sets indicates that these joints are of tectonic origin and they are probably the product of the same stress field that was responsible for the regional tilting. Joints that do not fall within these two patterns are probably a combination of tectonic longitudinal and cross joints and of non-tectonic cooling joints. Poorly developed columnar jointing was recognized in one outcrop.

Age

Moffit (1912) recovered Upper Triassic fossils from several limestone beds that crop out in the lower portion of the sedimentary section north of Windy Creek. Rose (1965) reports that in the Rainy Creek area the Amphitheatre basalts overlie Permian sediments and are considered Triassic.

No fossils were recovered from the section examined during the course of this study. On the basis of their stratigraphic position and apparent lateral correlation with the Amphitheatre basalts, a Triassic age is accepted for this section.

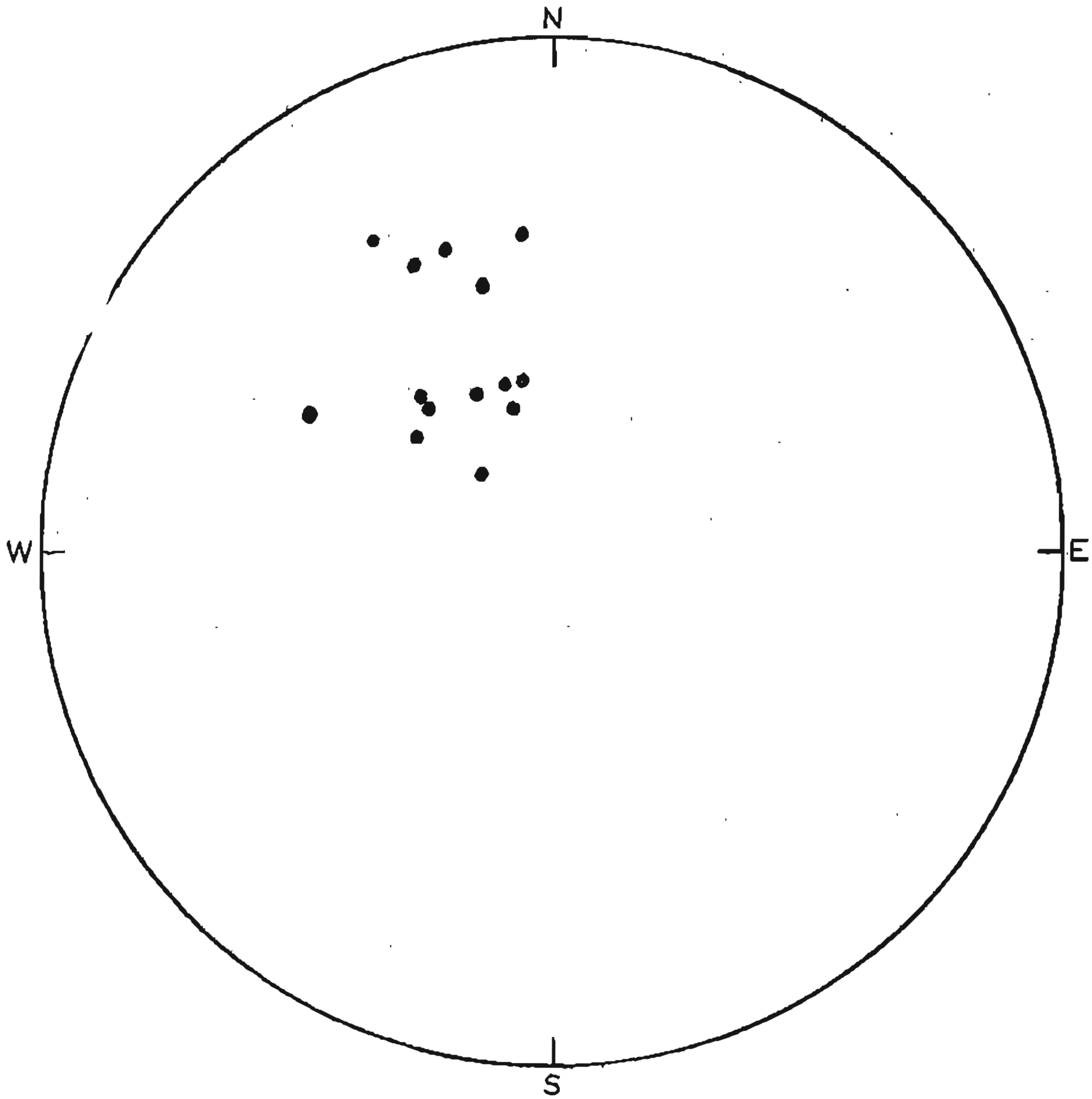

Figure 5. Pole positions for the flow layering and bedding, Clearwater Mountains, Alaska. Plotted on upper hemisphere of an equal area net.

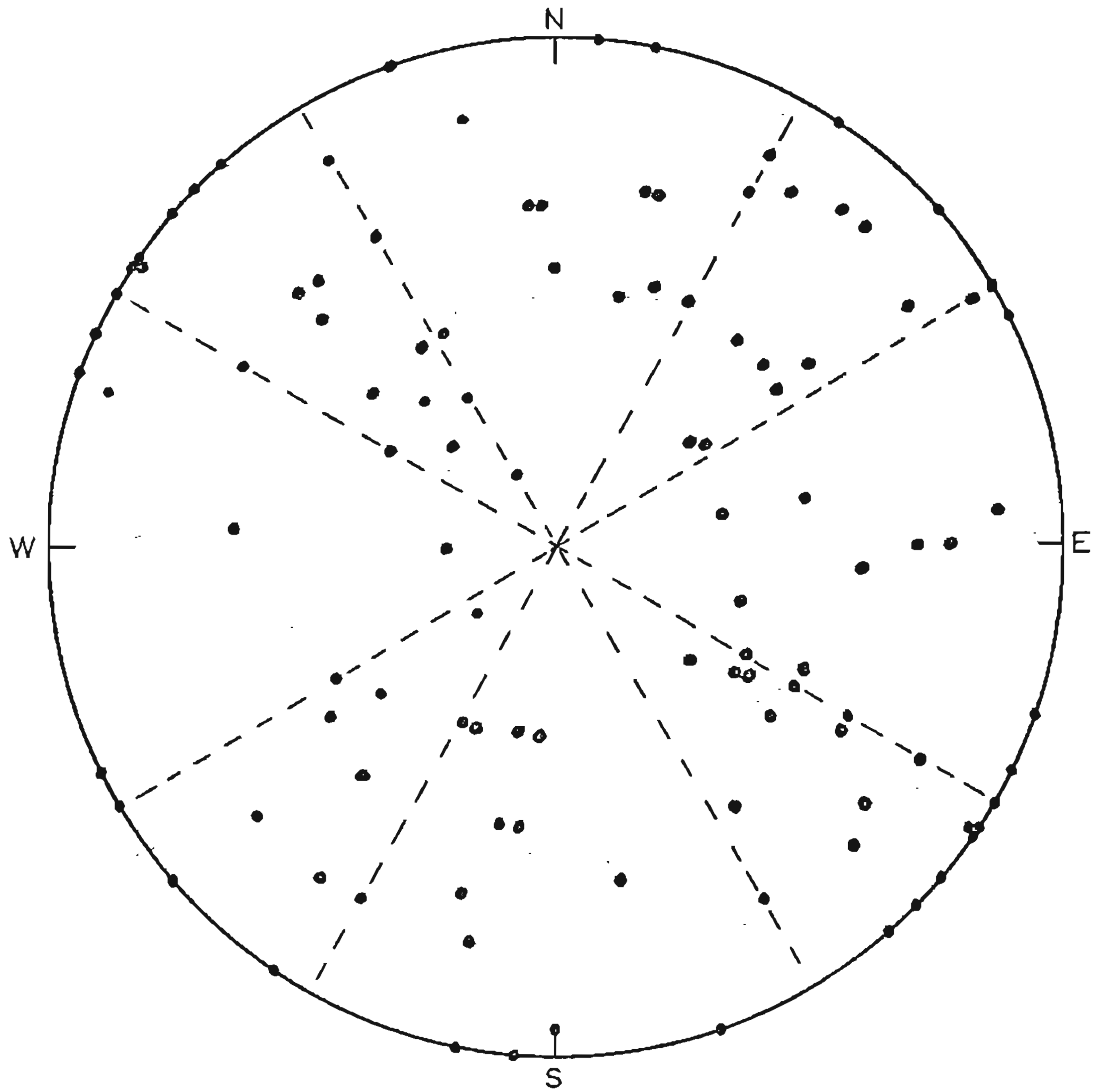

Figure 6. Ninety-three joint poles plotted on the upper hemisphere of an equal area net, Clearwater Mountains, Alaska. Dotted lines delineate major sets. Vertical joints appear twice.

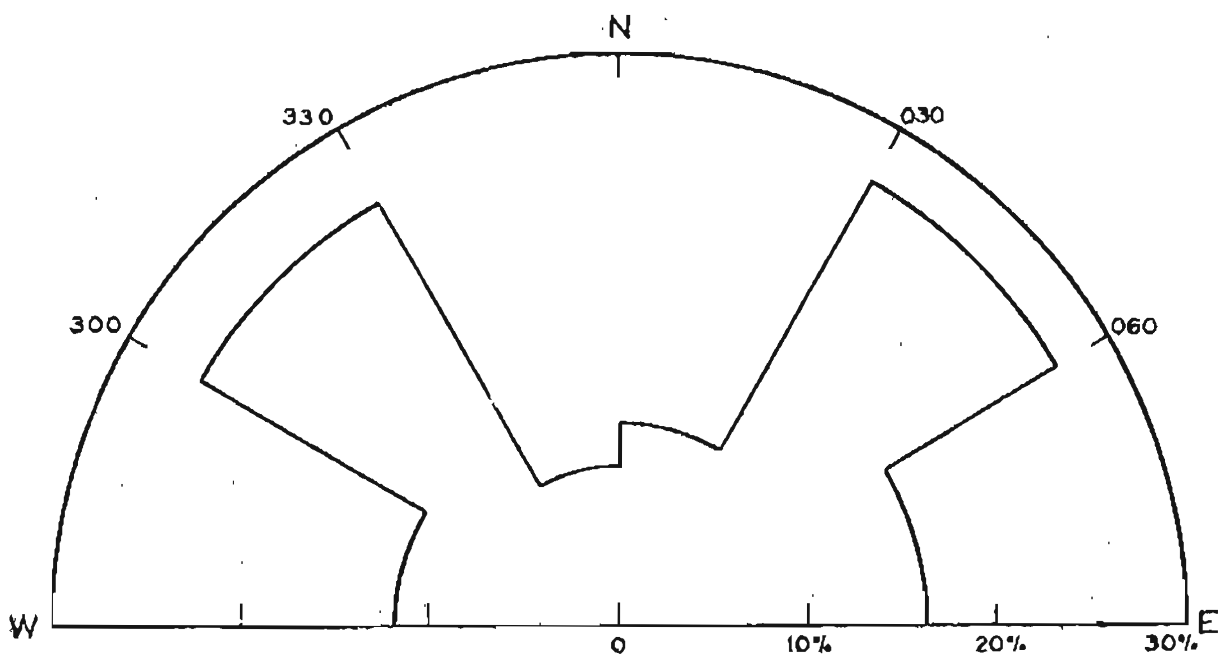

Figure 7. Strike frequency distribution of 93 joints, Clearwater Mountains, Alaska.

ECONOMIC GEOLOGY

Occurrence and Distribution of Copper Mineralization

Copper mineralization includes bornite, chalcocite, native copper, chalcopyrite and the supergene minerals malachite and azurite. Bornite is the most common and occurs as open space fillings in amygdules and discontinuous fractures, as splashes on joint faces and as a vein on the Greathouse property. Chalcocite occurs in amygdules and in small veins associated with quartz. Native copper is found as a disseminated mineral in the volcanic rocks and occasionally in amygdules associated with quartz. The native copper is easily detected on a freshly sawed surface but generally escapes recognition in the field. Chalcopyrite occurs as sporadic disseminated grains in the volcanic rocks and one chalcopyrite-quartz vein was observed. Chalcopyrite is not a common mineral in the map area. Malachite, and occasionally azurite, occurs associated with all the sulfides and also independently as splashes on joint faces.

Copper minerals were recognized at twelve different locations, ten of which are located in the northwest one-quarter of the map area (Plate II). At many of the locations the mineralized rock was found as float and could not be located in associated outcrops; however, the float is believed indicative of bedrock mineralization in the immediate vicinity.

The presence of native copper was detected only during the laboratory examination of field specimens. The location of specimens containing native copper is shown in Appendix II.

Description of Occurrences

Location 1 (location numbers refer to Plate II)

The mineralized sample was found in talus. The mineralization consists of malachite, minor chalcocite and bornite occurring in small quartz pods and stringers in an amygdaloidal andesite.

Location 2

Mineralized amygdaloidal andesite occurs in talus. Bornite, malachite and microscopic native copper associated with quartz pods occur in the andesite. The small quartz pods appear to have formed by replacement of the andesite. Bornite is later than the quartz and may, in part, be replacing it. Some of the strongly epidotized rock (greenstone) contains splashes of bornite, chalcocite (?) and malachite along fracture surfaces.

Location 3

Bornite, minor chalcocite and malachite occur as small discontinuous stringers in a narrow fracture zone. The fracture zone trends northeast, is about two inches wide and three feet in length. At both ends the zone narrows to a single fracture that continues along strike but is unmineralized. Gangue minerals include quartz and epidote. The paragenesis as determined in hand specimen is epidote, quartz, sulfides. The country rock is moderately altered andesite and is well jointed. Malachite coatings on joint faces are common.

Location 4

An amygdaloidal dike containing bornite as disseminated grains and occasionally amygdule filling. The dike rock is strongly altered (alteration index = 4) but appears to have been originally a diabase. Quartz, chlorite, epidote and carbonate also occur in the amygdules. Bornite in contact with chlorite appears to replace the chlorite but the contact between bornite and quartz is sharp and the two minerals appear contemporaneous. Bornite does not occur in contact with either epidote or carbonate in the thin section studied.

Location 5

Copper mineralization was frequently noted occurring in the float between stations S-5 and S-8 (Plate V). The country rock consists of intercalated andesite and basalt that is commonly strongly altered. Malachite stain, quartz and hematite were frequently observed on joint faces but no sulfides were observed in outcrop. In general the mineralized float consists of malachite and bornite associated with quartz in small vugs. Below station S-5 a piece of float containing cuprite, native copper, malachite and quartz as a thin coating on a fracture surface was observed. The float below station S-6 contains chalcocite. The chalcocite, associated with approximately equal amounts of quartz, occurs as a narrow (maximum width of two inches) vein in a block of moderately altered andesite. The float was traced to within five feet of the top of the talus slope but bedrock mineralization could not be located. Polished section study of the quartz-chalcocite vein indicates the chalcocite is primary and that it crystallized after quartz.

Location 6

Bornite, with associated malachite, quartz and epidote occurs as small stringers and blebs within a narrow shear zone. The zone trends east and is traceable for approximately twenty feet along strike before being obscured by rubble. Mineralization within the zone is erratic and slickensides indicate post-mineralization movement. The country rock is amygdaloidal greenstone and the fillings consist of pennine, quartz and epidote, with occasional bornite cores. Petrographic examination of the greenstone indicates a paragenetic sequence of pennine, epidote, quartz, bornite. Samples from the shear zone were slabbed and examined under a binocular microscope and were found to contain considerably more epidote, quartz and bornite than the adjacent greenstone.

Location 7

A fragmental volcanic unit, perhaps a flow breccia, cross-cut by frequent quartz veins. The veins range in width from one-half inch to six inches, are randomly oriented and occasionally contain discrete grains of bornite with associated malachite and azurite. Several strongly epidotized felsite dikes are also present. The entire outcrop is highly fractured and epidote is ubiquitous.

Location 8 Greathouse Prospect

The outcrop consists of variably altered (Plate VI) basalt and andesite flows. Bornite, chalcocite and covellite, with associated quartz, malachite, epidote and calcite occur in a northwesterly trending shear zone. At station G-1 (Plate VI) the zone is approximately three feet wide but it quickly narrows along strike and the mineralization becomes erratic. The wall rock is moderately altered basalt. Within the shear zone the fragmental country rock is strongly epidotized. A quartz bearing diorite dike (Table III) is located four feet northeast of the shear zone.

TABLE III

Estimated mode of quartz bearing diorite dike
based upon one thin section. Greathouse property.

Plagioclase (An_{35})	50%
Augite	25
Chlorite	10
Quartz	6
Hornblende and Uralite	<5
Magnetite	2
Carbonate	<1
Sphene	tr.
Apatite	tr.

The presence of secondary chlorite, carbonate and sericite suggests the dike is pre-regional alteration and is probably genetically related to the Raft Creek pluton. The dike parallels the strike of the shear zone and it probably controlled the location of the latter.

An examination of three polished sections indicates that quartz and bornite were the initial mineral phases (Fig. 8).

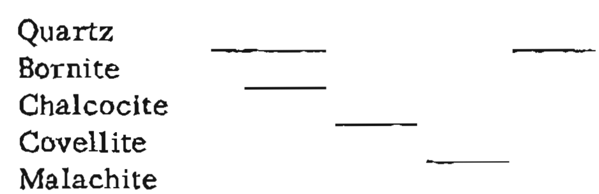

Figure 8. Paragenetic diagram based
on three polished sections. Greathouse prospect.

Chalcocite replaces bornite along secondary fractures and bornite-quartz contacts. It also replaces bornite, and to a limited degree the wall rock, along bornite-wall rock fragment contacts but does not replace quartz. Microscopic covellite replaces chalcocite in small chalcocite stringers and also occurs as discrete grains in wall rock fragments. Malachite, and probably the second generation quartz, are supergene. Calcite was not observed in the polished sections.

Location 9

The mineralization consists of malachite, subordinate azurite and rarely bornite occurring as stains and minor fracture fillings in a shear zone. The shear zone strikes east and is approximately three feet wide at its widest point. Mineralization is traceable for about thirty feet along strike but is sporadic. The country rock is moderately altered basalt. Several additional shear zones are present in the area but they appear to be unmineralized (Plate II).

Location 10

Malachite associated with quartz occurs as occasional splashes on slickensided joint faces along the cliff. No sulfides were observed. The outcrop is moderately altered basalt.

Location 11

Malachite stained amygdaloidal andesite was found in the talus. Bedrock consists of strongly altered basalt (alteration index = 3) that is cross-cut by a felsite dike.

Location 12

This location represents the only occurrence of copper mineralization recognized on the south side of the area. The mineralization consists of chalcopyrite, pyrite and malachite eratically distributed in quartz veins that cross-cut the diorite of the Raft Creek pluton. Numerous veins are present but only a few contain mineralization. The veins are randomly oriented and their width ranges from one-quarter inch to three inches. Although quartz veins frequently occur in the diorite, this location is the only one at which the veins are mineralized.

Trace Element Copper Distribution

General

The world average copper content of mafic rocks is reported by Vinogradov (1956a) to be 140 ppm (cited in Hawkes and Webb, 1962). Krauskopf (1955), from a survey of the literature, reports the average copper content of various sedimentary rocks as: sandstone 10-40 ppm, shale 30-150 ppm and black shale 20-300 ppm. The copper content of andesite agglomerate 40 miles east of the map area varies from 85 ppm to 170 ppm (Rose, 1966). Rose states that the stratigraphic relationship between the agglomerate and the Amphitheatre basalt is unclear, but he considers the agglomerate younger. Bateman and McLaughlin (1920), in a paper on the ore deposits of Kennecott, Alaska, point out:

> The greenstone itself, remote from ore bodies, invariably yields small amounts of copper by assay. J.D. Irving learned in 1906 from examination of many greenstone localities that hardly a greenstone specimen could be found which did not show appreciable copper, and numerous assays of greenstone from unmineralized areas showed .11 to .60 per cent. copper.

During the current study 132 samples, representing various rock types of the area, were analyzed spectrochemically and the results are shown in Appendix I. When compared with the world averages cited above, the copper content of the Clearwater Mountain rocks is abnormally high, and background for all rock types is approximately 1000 ppm. Values significantly higher than 1000 ppm can usually be attributed to visible copper minerals in the analyzed sample, e.g. samples S-10, 2-5, 9-1, etc. Exceptionally low values can be reproduced and a suggested explanation for these values is that the recovered field specimen is not representative of the sampled outcrop or that the outcrop represents a low copper content rock. This ambiguity could probably be removed by recovering and analyzing several samples per outcrop. Low values in the strongly altered rocks (alteration indexes 3 and 4) may, in part, represent local leaching of copper during alteration, however more detailed sampling of altered areas would be necessary to verify this.

The form in which the trace copper occurs was not determined. Trace element analysis of individual mineral phases from the Skaegaard instusion, East Greenland, indicates that plagioclase can contain up to 700 ppm copper and pyroxene up to 1000 ppm copper (Wagner and Mitchell, 1951). The authors further state:

> The steady increase and abrupt fall in the amount of copper shown by the successive plagioclase is also shown by the pyroxenes and the olivines. The sudden fall in copper content of the silicate minerals does not correspond to a fall in the copper content of the rocks, but it has been found that, at the stage when the amounts of copper in the silicate minerals becomes much reduced, sulfides become abundant in the rocks.

The copper present in the sedimentary rocks is probably a direct result of the ability of carbonaceous material to absorb the copper cation (Ong and Swanson, 1966). Although these sediments are believed to be the product of a shallow, nearshore environment, strong reducing conditions are to be expected in the presence of volcanic activity. The presence of hydrogen sulfide would result in the precipitation or secondary crystallization of sulfides, probably cupreous pyrite.

Areal Pattern

During the field portion of the study, samples of outcrop were taken at 1000 foot intervals along selected traverse lines. Initially the positions of the traverse lines were pre-selected to furnish a maximum of areal control, but many lines had to be relocated due to restrictions imposed by local topography. Usually one sample was taken per field station, but when variations in lithology were recognized, a sample of each compositional rock type was taken. The samples were analyzed spectrochemically for trace element copper and the results are shown on Plate III.

The distribution of trace copper within the map area is fairly uniform. Minor variations occur along individual traverses but areal trends appear to be lacking. The uniformity displayed by the distribution of trace copper strongly indicates a syngenetic origin for this pattern (Plate III). The copper that is present as trace quantities in the various rocks appears to be dominantly of primary origin, and there does not appear to have been any secondary redistribution of trace copper on an areal scale.

Local Patterns

Raft Creek (Plate IV)

The distribution of trace copper within the Raft Creek pluton is not uniform, and in the western outcrop the copper content appears to increase towards station 3B. This station represents the only occurrence of visible copper within the pluton (Location 12). The adjacent country rock shows a slight decrease in trace copper towards the pluton, but the pattern is believed to reflect the lithology of the analyzed samples (Appendix I) rather than leaching of copper during crystallization of of the pluton.

The trace copper of the pluton appears to be dominantly primary; however, some copper has been introduced with the secondary quartz veins. The emplacement of the pluton does not appear to have had a significant effect upon the areal distribution of trace copper (Plates III and IV).

Traverse S (Plate V)

Samples were taken at any recognized change in lithology or degree of alteration in the rock. The break between stations 17 and 19 represents a covered area. Outcrop consists of intercalated andesites and basalts that are generally strongly altered. The mean copper content of the seventeen samples is approximately 1000 ppm, the average background value. The higher values obtained at stations 5, 8 and 10 reflect the presence of bedrock mineralization (Locations 4 and 5).

Background values and rather uniform distribution suggests that the trace copper is dominantly of primary origin; however, the values obtained at stations 5, 8 and 10 are above background and appear to indicate very localized epigenetic copper.

Greathouse Prospect (Plates III and VI)

Trace copper values in the vicinity of the Greathouse prospect remain at or about background value. Traverse no. 7 of the areal pattern (Plate III) shows an increasing copper content towards station 7-4 but then rapidly drops off at station 7-5.

The trace copper values show no apparent indication of a high-copper aureole

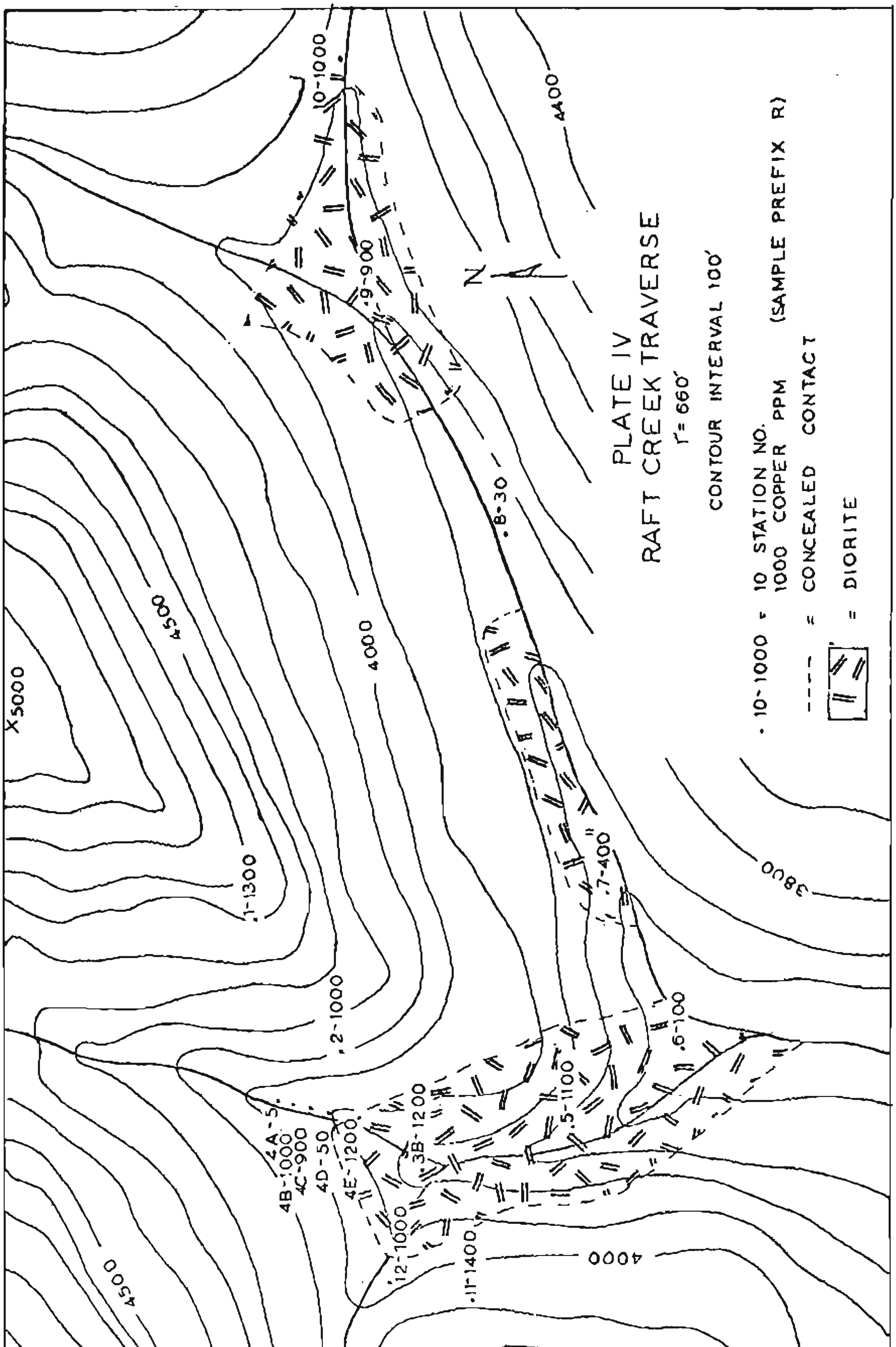
PLATE IV
RAFT CREEK TRAVERSE
1" = 660'
CONTOUR INTERVAL 100'
• 10-1000 = 10 STATION NO.
1000 COPPER PPM (SAMPLE PREFIX R)
- - - - = CONCEALED CONTACT
= DIORITE
N
4400
4500
X5000
4000
3800
4000
4500
10-1000
9-900
8-30
7-400
6-100
5-1100
3B-1200
4A-5
4B-1000
4C-900
4D-50
4E-1200
12-1000
11-1400
1-1300
2-1000

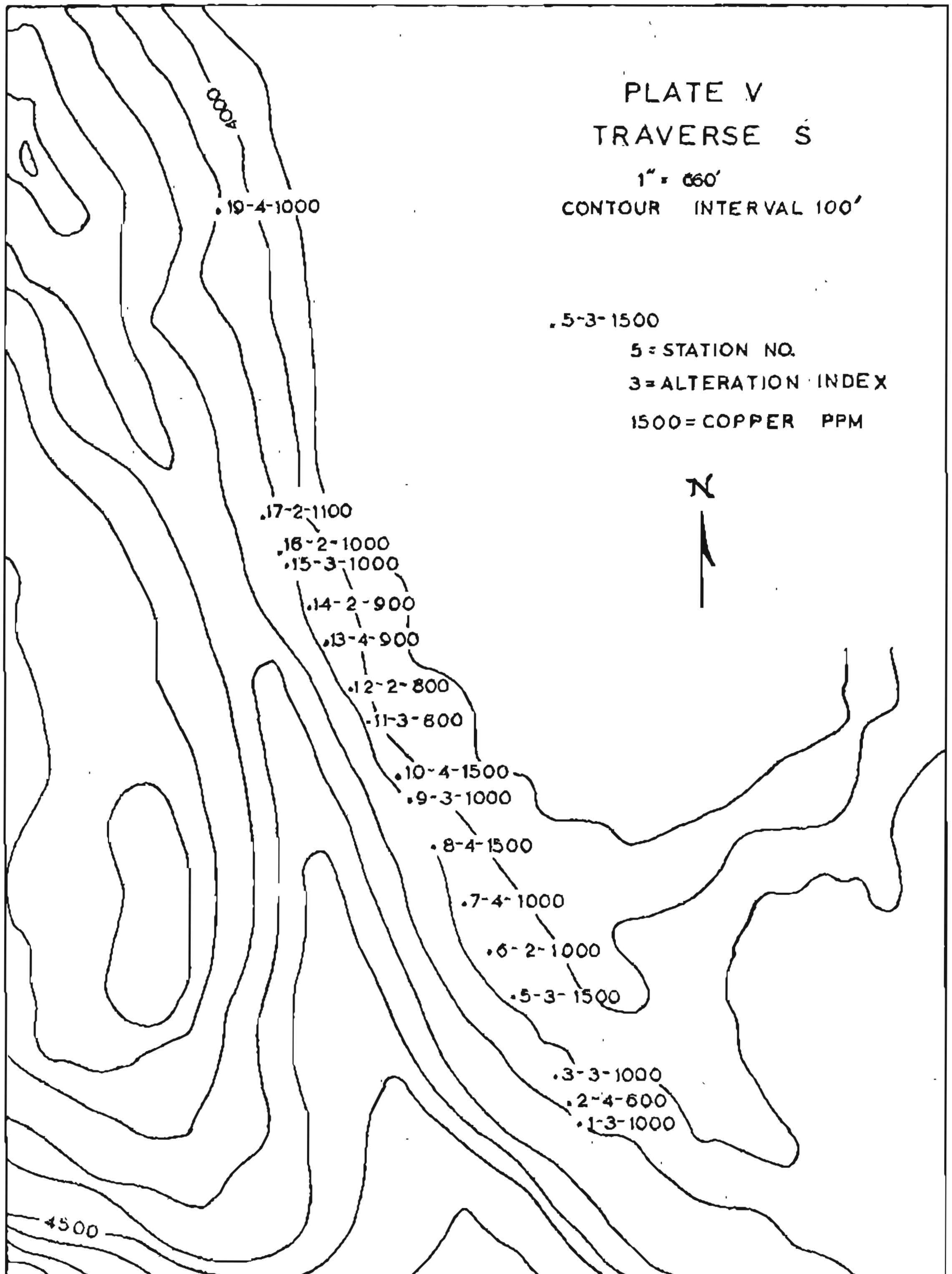
PLATE V
TRAVERSE S
1" = 660'
CONTOUR INTERVAL 100'
.5-3-1500
5 = STATION NO.
3 = ALTERATION INDEX
1500 = COPPER PPM
N
4000
4500
19-4-1000
17-2-1100
16-2-1000
15-3-1000
14-2-900
13-4-900
12-2-800
11-3-800
10-4-1500
9-3-1000
8-4-1500
7-4-1000
6-2-1000
5-3-1500
3-3-1000
2-4-600
1-3-1000

associated with the deposit, and the introduction of copper into the shear zone appears to have been very localized. Gouge, present along the walls of the shear zone, possibly formed an effective barrier to the mineralizing solutions. The marked difference in intensity of alteration between fragments of country rock within the shear zone and the wall rock substantiates this conclusion (Location 8). The increasing copper content shown along traverse no. 7 does not appear to be related to this copper deposit. The 1300 ppm copper value obtained at station no. 7-4 exceeds the mean value of the samples taken around the deposit and may be indicative of unrecognized bedrock mineralization.

Origin of Epigenetic Copper Deposits

Paragenesis

Petrographic examination of amygdules containing copper sulfides generally show sharp amygdule-host rock contacts with no visible interaction across the interface. Spectrochemical analysis of the host rocks, excluding the amygdules, usually yields values that are above background. Neither the areal nor local sampling patterns demonstrate a progressively decreasing copper content toward areas of known mineralization. Bedrock samples taken in the vicinity of mineralized shear zones and float occurrences commonly produce copper values that exceed background. When determinable, textural relationships indicate that alteration preceeded sulfide deposition. The tendency of copper minerals to occur in shear zones demonstrates that the zones were present prior to mineralization and served as channel ways for the copper bearing solutions.

The small deposits of copper sulfides are the product of deposition from

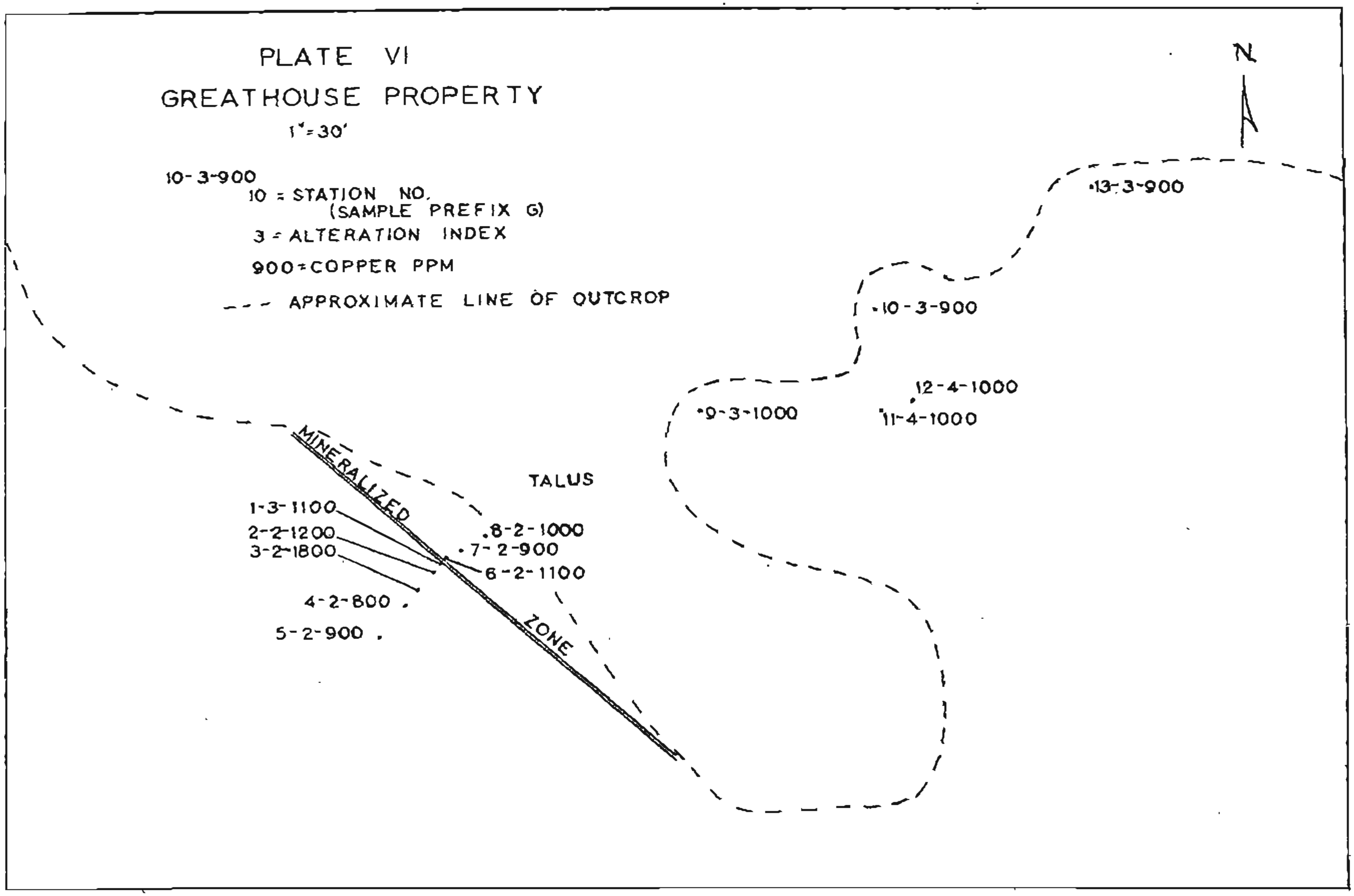
PLATE VI
GREATHOUSE PROPERTY
1" = 30'
10-3-900
10 = STATION NO. (SAMPLE PREFIX G)
3 = ALTERATION INDEX
900 = COPPER PPM
--- APPROXIMATE LINE OF OUTCROP
N
13-3-900
10-3-900
12-4-1000
11-4-1000
9-3-1000
TALUS
MINERALIZED ZONE
1-3-1100
2-2-1200
3-2-1800
4-2-800
5-2-900
8-2-1000
7-2-900
6-2-1100

introduced hydrothermal copper bearing solutions. The deposits appear to be mesothermal (McKinstry, 1959). The chemical composition of the mineralizing solutions appears to have been very similar to the fluids which produced the alteration, however considerably enriched in copper, sulfur and silica. The copper may have been derived from more distant high copper content volcanic rocks of this sequence, transported via solutions, and then re-deposited at the present sites of mineralization. A similar genesis has been suggested for the numerous small copper sulfide occurrences in the Nikolai greenstone (Bateman and McLaughlin, 1920).

Structural Control

The frequent occurrence of sulfide minerals associated with shear zones indicates that these structural features acted as channel ways for the copper bearing solutions. East and northeast trending zones were apparently the most receptive to the solutions as the existing deposits demonstrate a strong preference for these orientations. The proportionally higher number of mineral occurrences in the northwest one-quarter of the map area correlates favorably with an apparent increase in density of shear zones and highly fractured rocks in the same area. The continuity and behavior of the shear zones with depth is unknown.

Chemical Control

Sulfide mineralization shows no apparent preference for a particular compositional rock type, and replacement of wall rock by sulfides was observed only on a microscopic scale. The precipitation of copper sulfides from their transporting solutions, then, has apparently been a function of changes in temperature and pressure of the system and was not dictated by chemical reaction with the host rock along solution channel ways.

Economic Significance

The copper deposits examined during this study were all small, their size being restricted to the size of the open spaces available for sulfide deposition, and typically showed very little reaction with their host rocks. Additional copper occurrences undoubtedly exist within the volcanic rocks south of Windy Creek, but these too will probably possess similar characteristics to those previously described. They probably will be restricted in size to the size of the original channel ways and due to the apparent inert nature of the volcanic host rocks, large replacement deposits are not expected.

The deposits examined were formed by the deposition of copper from hydrothermal solutions that passed through the rocks along structurally controlled avenues. It is plausible that if the solutions were to come in contact with favorable host rocks, sizable replacement bodies could be formed. Such a situation has been documented for the well known Kennecott ore bodies (Bateman and McLaughlin, 1920). A similar geologic setting exists north of Windy Creek where limestone and argillite appear to overlie the volcanic sequence. Copper bearing fluids migrating through the volcanic sequence and into the more typically reactive calcareous rocks could feasibly produce commercial ore bodies. This view is substantiated by the location of the Denali prospect in the divide between

Windy Creek and South Fork Creek (not shown on included maps). Exploration drilling indicates that the deposit consists dominantly of chalcopyrite occurring as a replacement of limestone and argillite, but also includes chalcopyrite and bornite as open space filling in associated greenstone (D. Huber, 1966, oral communication). Exploration along the altered volcanic-sedimentary section contact has the potential of being quite profitable.

SUMMARY AND CONCLUSIONS

In the portion of the Clearwater Mountains examined during the course of this study the bedrock consists predominantly of intercalated andesitic and basaltic flows. Sedimentary rocks occur interbedded with the volcanic rocks in the vicinity of Raft Creek but comprise a very small percentage of the total section. The volcanic rocks appear to be the product of rather continuous volcanism with slight interruptions during which the sedimentary rocks were deposited. A small quartz bearing diorite pluton intrudes the volcanic and sedimentary rocks along Raft Creek.

Rock alteration within the area is not uniform. It may vary from weak to strong along the same traverse. Contacts between alteration types are usually gradational. The alteration is static thermal and was accompanied by aqueous fluids, the composition of which included magnesium, aluminum, iron, silica, calcium, carbon, copper, sulfur and water. Strongly altered rocks may yield either high or low copper values and a direct correlation between copper content and degree of alteration is not apparent.

The prevailing attitude of the volcanic and sedimentary rocks is east-northeast with a consistent north dip. Dip appears to increase toward the north. Shear zones and highly fractured areas are common and in the northwest one-quarter of the region have played a major role in the location of epigenetic copper deposits.

The trace copper content of all rocks is abnormally high and yield a background of 1000 ppm. The distribution of trace copper is fairly uniform and areal trends appear to be lacking. A syngenetic origin is suggested for the areal geochemical pattern. The copper that is present as trace quantitites in the various rocks appears to be dominantly of primary origin and there does not appear to have been any secondary redistribution of copper on an areal scale. High-copper aureoles associated with the epigenetic copper deposits are very local or nonexistent.

Epigenetic copper deposits are most common on the north side of the area. The deposits are the product of deposition from hydrothermal solutions that were introduced along pre-existing structural features. East and northeast trending shear zones were apparently the most receptive to the solutions. The copper deposits examined during this investigation were all small and although additional copper occurrences undoubtedly exist in the volcanic rocks south of Windy Creek, large replacement deposits are not expected.

The origin and structural control exhibited by the epigenetic copper deposits in this area indicates that exploration along the altered volcanic-sedimentary section contact north of Windy Creek has the potential of being quite profitable.

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APPENDIX I

Degree of alteration and copper content for various rock types sampled, Clearwater Mountains, Alaska.

Key to Table:

Rock Type
- V = volcanic rock
- S = sedimentary rock
- I = intrusive rock
- F = felsite dike
- Rock Name = petrographic analysis

Alteration Index
- 1 = weak alteration
- 2 = moderate alteration
- 3 = strong alteration
- 4 = very strong alteration

Sample Number
- 9-3 indicates traverse no. 9 sample no. 3.

Sample	Rock Type	Alter. Index	ppm Cu	Remarks
1-1	Andesite	2	25	
1-2	V	3	10	
1-3	V	2	900	
1-4	V	3	800	
1-5	Andesite	3	1000	
1-5A	Andesite	3	900	
1-6	V	2	1400	
1-7	V	2	1000	
1-8	Andesite	1	1000	
1-9	V	2	10	
1-10	V	3	900	
1-11	Greenstone	4	1100	
1-12	Andesite	4	1100	
2-1	Tuff	4	40	
2-3	V	3	900	
2-4A	Greenstone	4	600	
2-4B	Ash	3	10	

Sample	Rock Type	Alter. Index	ppm Cu	Remarks
2-5	V	3	1700	visible sulfides
2-6	Tuff (?)	4	30	
2-7	V	4	900	
2-8	Andesite	1	800	
3-1	Basalt	2	1000	
3-2	V	4	1000	
3-3A	V	3	800	
3-3B	Basalt	2	600	
3-4	V	3	1000	visible sulfides
3-5	Greenstone	4	800	
3-15	Andesite	2	20	
3-16	V	4	1400	
3-17	Greenstone	4	1400	
3-17A	Greenstone	4	40	
3-18	V	2	5	
3-19	V	3	800	
3-20	Andesite	2	700	
3-20A	Carbonate vein	-	800	
4-1	Greenstone	4	20	
4-2	V	2	1100	
4-2A	Carbonate Vein	-	700	
4-3	Andesite	2	20	
4-4	V	3	1100	
4-4A	V	3	900	
4-5	V	3	5	
4-6	Gabbro	1	40	
4-7	V	3	10	
5-1	V	1	1100	
5-2A	Black Shale	-	5	
5-2B	S	-	900	carbonaceous
5-3	V	2	1100	
5-4	Greenstone	4	20	
5-5	V	2	5	
5-6	S	-	1000	
5-6A	Mudstone	-	20	
5-6B	V	2	5	
5-7	S	-	10	
7-1	Greenstone	3	600	
7-2	V	1	900	

Sample	Rock Type	Alter. Index	ppm Cu	Remarks
7-3	V	2	1100	
7-4	V	2	1300	
7-5	Basalt	2	600	
9-1	V	2	1500	native Cu
9-2	V	2	1200	
9-3	V	2	1300	
9-4	V	2	1300	
9-5	V	3	20	
9-5A	V	3	1100	
9-6	V	2	1200	
9-7	V	2	1500	visible sulfides
9-8	V	2	1200	
9-9	V	2	1000	
9-10	V	2	1300	
9-13	V	3	20	
9-14	Andesite	3	5	
9-15	Greenstone	4	50	
9-15A	V	3	1100	
9-16	V	3	1000	
11-1	Basalt	1	30	
11-1A	V	3	1200	visible sulfides
11-2	V	3	1300	
11-3	V	3	1300	
11-3A	F	1	5	
11-4	V	2	1200	
11-5	V	2	1200	
11-6	V	2	1400	
11-7	V	2	1400	
G-1	V	3	1100	
G-2	V	2	1200	native Cu
G-3	V	2	1800	much native Cu
G-4	V	2	800	
G-5	V	2	900	
G-6	V	2	1100	
G-7	I	2	900	dike
G-8	Diorite	2	1000	dike
G-9	V	3	1000	
G-10	V	3	900	native Cu in amygdule
G-11	V	4	1000	
G-12	V	4	1000	
G-13	V	3	900	native Cu in amygdule

Sample	Rock Type	Alter. Index	ppm Cu	Remarks
R-1	S	-	1300	
R-2A	Sandstone	-	800	carbonaceous
R-2B	S	-	1000	
R-3B	Diorite	4	1200	pluton
R-4A	S	-	5	mudstone
R-4B	S	-	1000	visible sulfides
R-4C	S	-	900	visible sulfides
R-4D	Mudstone	-	50	
R-4E	Diorite	3	1200	pluton
R-5	I	3	1100	
R-6	Diorite	4	100	
R-7	I	3	400	
R-8	V	2	30	glassy flow rock
R-9	I	4	900	
R-10	S	-	1000	visible sulfides
R-11	Diorite	4	1400	late dike
R-12	S	-	1000	
S-1	V	3	1000	
S-2	Greenstone	4	600	
S-3	V	3	1000	native Cu
S-5	V	3	1500	
S-6	V	2	1000	
S-7	V	4	1000	
S-8	Greenstone	4	1500	
S-9	V	3	1000	
S-10	Greenstone	4	1500	amygdaloidal dike with visible bornite
S-11	V	3	800	
S-12	V	2	800	
S-13	V	4	900	
S-14	V	2	900	
S-15	V	3	1000	
S-16	V	2	1000	
S-17	V	2	1100	
S-19	V	4	1000	

APPENDIX II

Sample Preparation and Analytical Technique

Samples analyzed for trace copper were prepared in the following manner:

A diamond saw was used to cut a chip of the rock specimen, weathering rind was trimmed away as were copper bearing amygdules, when present. The chip was then ground by hand in a stainless steel mortar to approximately 100 mesh. The mortar and pestle were cleaned with hydrocloric acid and rinsed with demineralized water prior to grinding each sample. The 100 mesh material was coned and quartered and approximately 500 milligrams of this material removed for finer grinding. Second stage grinding was done in a small stainless steel ball mill that employed a "Wig-L-Bug" for agitation. The mill reduced the sample to -200 mesh. Ten milligrams of the -200 mesh material were mixed with an equal weight of spectroscopically pure graphite powder and packed into an L4261 standard Harvey electrode. The sample electrode was then placed in a muffle furnace at 600° C for fifteen minutes to remove all moisture. An L3960 electrode was used as the anode.

The prepared electrodes were fired in a Jarrel-Ash 1.5 meter Wadsworth Grating Spectrograph using the following excitation conditions:

Type of excitation:	D.C. Arc
Amperage:	9.5 amps (maximum)
Method of ignition:	Contact
Electrode gap:	4 mm initially, allowed to widen with burning time
Slit width:	25 microns (fixed) 6 mm slit over columating mirror

Exposure time:	2 minutes (no pre-burn)
Spectrum width:	2 millimeters
Filter:	Step 4 density filter
Film:	Kodak Spectrum Analysis No. 1

The samples were fired in groups of seven with one of the seven selected arbitrarily and fired as a reproducibility check. The seven samples were chosen at random to remove personal bias during analysis of the film.

Copper concentration was determined from copper lines 2961 and 3273 by the line to background density method using sensitivity factors for a silicate matrix. The method is semi-quantitative with an expected accuracy of ± 30 to 50% of the amount reported. (Harvey, 1964) Reproducibility was always within ± 30% of the value obtained on the first firing and commonly within ± 10%.